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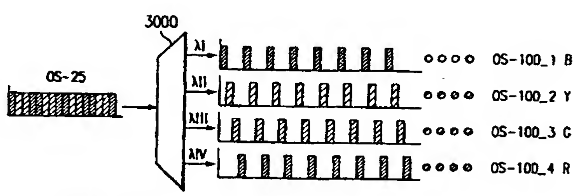

OPTICAL SLICING

1	OS-25	200*2.5 Gbps
2	OS-50	100*2.5 Gbps
4	OS-100	50*2.5 Gbps
8	OS-200	25*2.5 Gbps

ASSUMING EDFA 40 nm BAND

SONET

1	OC-192	10 Gbps
4	OC-48	2.5 Gbps
16	OC-12	622 Mbps
64	OC-3	155 Mbps

(57) Abstract: An optical wavelength add/drop multiplexer provides communications between two optical links supporting wavelength division multiplexing (WDM). A wavelength slicer spatially separates the input signal into two sets of channels. An optical filter, such as an interference filter, spatially separates the subset of the input channels into an array of separated channels. A programmable optical add/drop switch array selectively routes channels from and array of input ports to an array of drop ports, substitutes channels from an array of add ports in place of the dropped channels, and routes the ramaining input channels and added channels to an array of output ports. The channels from the output ports of the said add/drop switch array are then combined and transmitted into the second optical link. In an alternative embodiment, a circulated drop filter consisting of an optical circulator and a series of filter Bragg gratings is used to select a predetermined series of input channels to be processed by the add/drop switch array, with the remaining channels being passed by the circulated drop filter as express lanes.

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OPTICAL SLICING NETWORK UTILIZING A HIGH EXTINCTION RATIO POLARIZATION BEAMSPLITTER

RELATED APPLICATIONS

The present application is a continuation-in-part of the Applicant's co-pending U.S. Patent Application Serial Number 08/780,291, entitled "SWITCHABLE WAVELENGTH ROUTER," filed on January 8, 1997, which is hereby incorporated herein by reference; and U.S. Patent Application Serial Number 09/273,920, entitled "OPTICAL WAVELENGTH ADD/DROP MULTIPLEXER," filed on March 22, 1999, which is hereby incorporated herein by reference, and is related to co-pending U.S. Serial Number 09/190,078, entitled "SYSTEM FOR DEALING WITH FAULTS IN AN OPTICAL LINK," filed on November 12, 1998, which is hereby incorporated herein by reference; Attorney Docket Number 55872-P048US-992837, entitled "HIGH EXTINCTION RATIO POLARIZATION BEAMSPLITTER," which is hereby incorporated herein by reference; Attorney Docket Number 55872-P046CP1CP1-993118, entitled "N X M DIGITALLY PROGRAMMABLE OPTICAL ROUTING SWITCH USING HIGH EXTINCTION RATIO POLARIZATION BEAM SPLITTER," which is hereby incorporated herein by reference; Attorney Docket Number 55872-P043CP1-993120, entitled "FIBER OPTIC SMART SWITCH," which is hereby incorporated herein by reference; Attorney Docket Number 55872-P042CP2CP1-993119, entitled "OPTICAL ADD/DROP WAVELENGTH SWITCH USING A HIGH EXTINCTION RATIO POLARIZATION BEAMSPLITTER," which is hereby incorporated herein by reference.

TECHNICAL FIELD

The present application relates in general to optical communications, and in specific to using a wavelength slicer for wavelength division multiplex communications.

BACKGROUND

Optical wavelength division multiplexing has gradually become the standard backbone network for fiber optic communication systems. WDM systems employ signals consisting of a number of different wavelength optical signals, known as carrier signals or channels, to transmit information over optical fibers. Each carrier signal is modulated by one or more information signals. As a result, a significant number of information signals may be transmitted over a single optical fiber using WDM technology. These optical signals are repeatedly amplified by erbium-doped fiber amplifiers (EDFA) along the network to compensate for transmission losses. The amplified signals reach the receiving end and are detected using WDM filters followed by photo receivers.

Fiber optic communications networks are typically arranged with a plurality of terminals in any of a number of topological configurations. The simplest configuration is two terminals communicating data over an optical link. This can be extended to a daisy-chain configuration in which three or more terminals are connected in series by a plurality of optical links. Ring configurations are also used, as well as other two-dimensional mesh networks. In each case, the optical link between two terminals typically includes a plurality of optical fibers for bidirectional communications, to provide redundancy in the event of a fault in one or more of the optical fibers, and for future capacity.

Despite the substantially higher fiber bandwidth utilization provided by WDM technology, a number of serious problems must be overcome, for example, multiplexing, demultiplexing, and routing optical signals, if these systems are to become commercially viable. The addition of the wavelength domain increases the complexity for network management because processing now involves both filtering and routing. Multiplexing involves the process of combining multiple channels (each defined by its own frequency spectrum) into a single WDM signal. Demultiplexing is the opposite process in which a single WDM signal is decomposed into individual channels or sets of channels. The individual channels are spatially separated and coupled to specific output ports. Routing differs from demultiplexing in that a router spatially separates the input optical channels to output ports and permutes these channels according to control signals to create a desired coupling between an input channel and an output port.

Note that each carrier has the potential to carry gigabits of information per second. Current technology allows for about forty channels or optical carriers, each of a slightly different wavelength, to travel on a single-mode fiber using a single WDM signal. The operating bands are limited by the EDFA amplifier (C) band, thus the increase in the number of channels has been accomplished by shrinking the spacing between the channels, and by adding new bands. The current standard is 50 and100 GHz between optical channels, whereas older standards were 200 and 400 GHz spacings. Another characteristic of the WDM signal is the modulation rate. As the modulation rate is increased, more data can be carried. Current technology allows for a modulation rate of 10 Gigabits per second (Gbs). This has been recently increased from 2.5 Gbs. The 10 Gbs standard is SONET OC-192, wherein SONET is synchronized optical network and OC is optical carrier. The increase in the modulation rate translates into a wider signal in the spatial domain. Consequently, the wider signal and smaller spacing means that the signals are very close together (in the spatial domain), and thus are very hard to separate. As a result, crosstalk may occur from adjacent signals.

One prior art separation method is to divide the spatial band into four sub-bands, each about 200 GHz wide. The filters used to perform the separation have significant side slopes (i.e., they produce trapezoidal shapes), and thus overlap occurs between the bands. To prevent crosstalk, guard bands are placed at the boundaries of the sub-bands, where no signals are placed. These guard bands consume significant bandwidth, i.e., about 30%. Additional stages could be added to achieve 100 GHz bands, but this increases the bandwidth consumed by the guard bands.

Also dropping and adding channels is a problem. For example, in a group of 16 carrier channels, 4 might need to be dropped for distribution to a local metropolitan area and the other 12 carrier channels might need to be passed on to other remote destinations. This is typically accomplished by demodulating all 16 optical carriers to obtain 16 electronic signals, then remodulating the 12 carriers and processing the 4 electrical signals. Optical-to-electrical (O-E) converters are used at switching centers to demodulate all the optical signals, including those not intended for local distribution. The "long-haul" signals are processed to modulate a laser (E-O) converter for launch into optical fiber to their ultimate destinations. The channels vacated by taking off signals for local distribution can now be filled by new carriers to move signals from local switches to remote destination. These electrical-to-optical-to-electrical

(OEO) "add/drop" operations are critical to network performance but require that all carriers on a fiber be demodulated, processed, and remodulated in order to pick off even a small fraction of the data flowing on the fiber. In the current art, there is no effective non-OEO method of simultaneously dropping a DWDM carrier with mixed traffic for local distribution while simultaneously passing the carrier through to a remote location.

SUMMARY OF THE INVENTION

This invention provides an optical wavelength add/drop multiplexer for communications between two optical links supporting wavelength division multiplexing (WDM). A wavelength slicer spatially separates the input signal into two sets of channels. An optical filter such as an interference filter, spatially separates the set of the input channels into an array of separated channels. A programmable optical add/drop switch array selectively routes channels from an array of input ports to an array of drop ports, substitutes channels from an array of add ports in place of the dropped channels, and routes the remaining input channels and added channels to an array of output ports. The channels from the output ports of the said add/drop switch array are then combined and transmitted into the second optical link. A network of wavelength slicers can be used to spatially separate the input signal into a larger number of sets of channels that can either be accessed by a number of add/drop switch arrays, or pass unchanged as "express lanes" to the second optical link. In an alternative embodiment, a circulated drop filter consisting of an optical circulator and a series of fiber Bragg gratings is used to select a predetermined series of input channels to be processed by the add/drop switch array, with the remaining channels being passed by the circulated drop filter as express lanes.

A primary object of the present invention is to provide an optical wavelength add/drop multiplexer that can separate multiple channels from an input WDM signal and selectively substitute channels from series of add ports in place of the input channels.

Another object of the present invention is to provide an optical wavelength add/drop multiplexer that can be used to augment the channel capacity of an existing central office equipment for optical communications.

These and other advantages, features, and objects of the present invention will be more readily understood in view of the following detailed description and the drawing.

The foregoing has outlined rather broadly the features and technical advantages of the present invention in order that the detailed description of the invention that follows may be better understood. Additional features and advantages of the invention will be described hereinafter which form the subject of the claims of the invention. It should be appreciated by those skilled in the art that the conception and specific embodiment disclosed may be readily utilized as a basis for modifying or designing other structures for carrying out the same

purposes of the present invention. It should also be realized by those skilled in the art that such equivalent constructions do not depart from the spirit and scope of the invention as set forth in the appended claims.

BRIEF DESCRIPTION OF THE DRAWING

For a more complete understanding of the present invention, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawing, in which:

FIGURES 1A and 1B are simplified block diagrams illustrating the functionality of the wavelength slicers;

FIGURE 2 is a schematic block diagram of a wavelength slicer;

FIGURE 3 is a spectral diagram of the transmission function of a wavelength slicer for separating adjacent 50 GHz input channels into two sets of output channels;

FIGURE 4 is a spectral diagram of the transmission function of a wavelength slicer for separating adjacent 50 GHz input channels into two sets of output channels;

FIGURE 5 depicts a smart switch utilizing a high extinction ratio polarization beamsplitter;

FIGURE 6 depicts a 4 x 4 add/drop switch array;

FIGURE 7 depicts two 4 x 4 add/drop switch arrays forming an arbitrary add/drop switch;

FIGURE 8 depicts a 4 x4 add/drop switch with wavelength conversion;

FIGURE 9 depicts a drop/add switch for wavelength management and restoration;

FIGURE 10 depicts a multi-ring network system;

FIGURE 11 depicts the a OS-200 signal being sub-divided into four OS-800 signals;

FIGURE 12 depicts wavelength slot interchange; and

FIGURE 13 depicts a mesh network system.

DETAILED DESCRIPTION

A WDM signal consists of multiple channels with each channel having its own range of wavelengths or frequencies. As used herein, the terms "channel" or "spectral band" refer to a particular range of frequencies or wavelengths that define a unique information signal. Each channel is usually evenly spaced from adjacent channels, although this is not necessary. For example, the wavelength slicers shown in FIGURE 1 can separate channels based on a 50 GHz spacing between adjacent channels, as depicted in FIGURE 3. Uneven spacing may result in some complexity in design, but, as will be seen, the present invention can be adapted to such a channel system. This flexibility is important in that the channel placement is driven largely by the technical capabilities of transmitters (i.e., laser diodes) and detectors and so flexibility is of significant importance.

The sets of input WDM channels are mutually exclusive, in that there is no overlap in the frequency bands assigned to channels in the different sets. In the preferred embodiment of the present invention, the first and second sets of channels are interdigitally spaced as shown in FIGURE 1. For example, the spacing between adjacent channels in the first set can be 100 GHz, and the spacing between adjacent channels in the second set can be 100 GHz. The resulting interdigital spacing between channels after the first and second sets are combined would be 50 GHz. This type of arrangement allows for network planning. Consider the one 50 GHz signal to comprise two 100 GHz signals or four 200 GHz signals. Similarly, one 25 GHz signal comprises two 50 GHz signal or comprise four 100 GHz signals or eight 200 GHz signals or sixteen 400 GHz signals. These signals can be divided as needed to handle different situations. Note that other channel configurations could be employed, as long as there are at least two mutually exclusive sets of channels. For example, alternating blocks of channels could be used to define the first and second sets of channels.

FIGURE 1A is a block diagram illustrating the general functionality of an individual wavelength slicer 100 as a component in a larger network system. The input WDM signal is coupled using conventional optical signal coupling techniques to the input port of the wavelength slicer 100. The wavelength slicer 100 separates the input signal into two sets of channels, which are routed to the output ports as depicted in FIGURE 1A. FIGURE 1B depicts a 1 x 4 slicer 3000. The input signal is a 25 GHz spaced signal, OS-25, which is divided into

four 100 GHz signals by slicer 3000. Note that each of these signals are orthogonal to each other, i.e. they do not overlap. Also note that they are synchronized in the wavelength domain. This 1 x 4 slicer can be constructed by cascading two 1 x 2 slicers of FIGURE 1A.

In the preferred embodiment, the wavelength slicer 100 separates alternating adjacent input channels into the first and second sets of output channels. FIGURE 3 illustrates the transmission characteristics of a wavelength slicer with a channel spacing of 50 GHz. Each wavelength slicer 100 is inherently bidirectional, and therefore can be used interchangeably either to separate (or demultiplex) an input signal into two sets of output channels, or to combine (or multiplex) two sets of input channels into a combined output WDM signal. Note that no guard bands are needed. Moreover, the system is scalable, e.g. when a 25 GHz spacing is available, a 25GHz slicer is attached in front of the 50 GHz slicer and a second 50 GHz slicer network may be added to the 25 GHz network. Further note, that by separating the adjacent channels, good isolation between adjacent channels is achieved.

FIGURE 2 depicts the details of the structure and operation of one possible implementation of a wavelength slicer, for other implementations see "SWITCHABLE WAVELENGTH ROUTER," U.S. Application Serial Number 08/780,291, filed January 8, 1997, which is hereby incorporated herein by reference.

FIGURE 2 is a detailed schematic diagram of a wavelength slicer 100. Each of the optical paths is labeled with either a horizontal double-headed line indicating horizontal polarization (p polarization), or a vertical double-headed line indicating vertical polarization (s polarization, which may be depicted as "•"), or both horizontal and vertical double-headed lines indicating mixed horizontal and vertical polarizations in the optical signal at that point.

The input signal 101 enters the first birefringent element 102 that spatially separates horizontal and vertically polarized components of the input signal. The first birefringent element 102 comprises a material that allows the vertically polarized portion of the optical signal to pass through without changing course because they are ordinary waves in the birefringent element 102. In contrast, horizontally-polarized waves are redirected at an angle because of the birefringent walk-off effect. The angle of redirection is a well-known function of the particular materials chosen. Examples of materials suitable for construction of the birefringent element include calcite, rutile, lithium niobate, YVO_4-based crystals, and the like.

The horizontally-polarized component travels along a path 201 as an extraordinary signal in the first birefringent element 102 while the vertically polarized component 202 travels as an ordinary signal and passes through without spatial reorientation. The resulting signals 201 and 202 both carry the full frequency spectrum of the input signal 101.

At least one of the beam components 201 and 202 are coupled to a polarization rotator 103 which selectively rotates the polarization state of either beam component 201 or 202 by a predefined amount. In the preferred embodiment, the rotator 103 rotates the signals by either 0° (i.e., no rotation) or 90°. In FIGURE 2, the vertically-polarized component 202 is rotated by 90° so that both signals 203, 204 exiting the polarization rotator 103 have a horizontal polarization. Again, at this stage, both the horizontal and vertical components 202, 203 contain the entire frequency spectrum of channels in the input WDM signal 101.

The stacked waveplates element 104 is a stacked plurality of birefringent waveplates at selected orientations that generate two eigen states. The first eigen state carries a first set of channels with the same polarization as the input, and the second eigen state carries a complementary set of channels at the orthogonal polarization. The polarization of the incoming beam and the two output polarizations form a pair of spectral responses, where (H, H) and (V, V) carry the first set of channels from the input spectrum and (H, V) and (V, H) carry the complementary (second) set of channels of the input spectrum, where V and H are vertical and horizontal polarization, respectively. With horizontal polarizations 203, 204 input to the first stacked waveplates element 104 as illustrated in FIGURE 2, orthogonal vertical and horizontal polarizations are generated with the first set of channels residing in horizontal polarization and the second set of channels residing in vertical polarization.

The pairs of optical responses 205, 206 output by the first stacked waveplates element 104 are coupled to a second birefringent element 105. This birefringent element 105 has a similar construction to the first birefringent element 102 and spatially separates the horizontally and vertically polarized components of the input optical signals 205 and 206. The optical signals 205, 206 are broken into vertically-polarized components 207, 208 containing the second set of channels and horizontally-polarized components 209, 210 containing the first set of channels. Due to the birefringent walk-off effect, the two orthogonal polarizations that

carry first set of channels 209, 210 in horizontal polarization and second set of channels 207, 208 in vertical polarization are separated by the second birefringent element 105.

Following the second birefringent element 105, the optical elements on the input side of the second birefringent element 105 can be repeated in opposite order, as illustrated in FIGURE 2. The second stacked waveplates element 106 has substantially the same composition as the first stacked waveplates element 104. The horizontally-polarized beams 209, 210 input to the second stacked waveplates element 106, are further purified and maintain their polarization when they exit the second stacked waveplates element 106. On the other hand, the vertically-polarized beams 207, 208 experience a 90° polarization rotation and are also purified when they exit the second stacked waveplates element 106. The 90° polarization rotation is due to the fact that the vertically-polarized beams 207, 208 carry the second set of channels and are in the complementary state of stacked waveplates element 106. At the output of the stacked waveplates element 106, all four beams 211, 212 and 213, 214 have horizontal polarization. However, the spectral bands defined by the filter characteristics of the stacked waveplates elements 104, 106 are separated with the second set of channels on top and the first set of channels below.

To recombine the spectra of the two sets of beams 211, 212 and 213, 214, a second polarization rotator 107 and a third birefringent element 108 are used. The second rotator 107 intercepts at least two of the four parallel beams 211 - 214 and rotates the polarization of the beams to produce an orthogonally-polarized pair of beams 215, 216 and 217, 218 for each spectral band at the output of the second polarization rotator 107. In the case of FIGURE 2, the polarization of beams 211 and 213 is rotated by 90°, and beams 212 and 214 are passed without change of polarization. Finally, a third birefringent element 108 recombines the two orthogonally-polarized beam pairs 215, 216 and 217, 218 using the walk-off effect to produce two sets of channels that exit at the output ports 109 and 110, respectively.

The slicer shown in FIGURE 2 can be used to slice a WDM signal into bands, each of which comprises a plurality of wavelength channels, additional slicers would be used to separate the bands down to individual channels. This is depicted in FIGURE 4.

FIGURE 4 provides an overall schematic diagram 400 of an embodiment of the present invention using two networks 301 and 401 of wavelength slicers. Input WDM signals 10 from

an optical link are coupled to the input port of a first wavelength slicer 302. The input WDM signal comprises multiple channels with each channel having its own range of wavelengths or frequencies.

Each wavelength slicer 302 - 306 in the wavelength slicer network 301 spatially separates a set of input WDM channels into two complementary sets of output channels. In the preferred embodiment, each wavelength slicer separates alternating adjacent input channels into first and second sets of output channels as shown in FIGURE 1. The first wavelength slicer 302 separates the network input signal 10 into a first set of channels 11 that are routed to wavelength slicer 303, and a second set of channels 12 that are routed to wavelength slicer 304. For example, the initial wavelength slicer 302 can separate channels based on a 50 GHz spacing between adjacent channels.

The first set of channels output by the initial wavelength slicer 302 is routed along a first optical path 11 to second and third stage wavelength slicers 303, 305, and 306. The second set of channels output by the initial wavelength slicer 303 is routed along a second optical path 12 to wavelength slicer 304. The second state of wavelength slicers 303, 304 further separate the input channels into four sets of channels. For example, the second state of wavelength slicers 303, 304 separates channels based on a 100 GHz spacing between adjacent channels. This process can be continued by cascading additional stages of wavelength slicers to achieve up to 2N sets of channels, where N is the number of stages. For example, the wavelength slicer network 301 has a partial third state consisting of wavelength slicers 305 and 306.

The output channels from wavelength slicer 304 exit the first wavelength slicer network 301 along optical path 13 without further processing. These output channels are referred to as "express lanes" and pass directly to the second wavelength slicer network 401 used to recombine the optical signals that are to be returned to the optical network, as will be discussed below. Optionally, wavelength slicers 304 and 404 could be eliminated so that the second set of optical signals from the initial wavelength slicer 302 would serve as the express lanes and pass directly to the final wavelength slicer 402 in the second wavelength slicer network 401.

The first set of channels are further subdivided into four sets of channels that are received as inputs by an array of optical filters 307, 308, 309, and 310. These optical filters

307 - 310 separate the input sets of channels into an array of separated channels. The implementation shown in FIGURE 4 is based on commercially-available interference filter arrays that can separate up to eight channels. However, other types of optical filters can be employed for spatially separating the channels. The type of optical filter used and the number of filters in the array are purely matters of convenience of design. As an alternative, additional slicers could be used.

The array of separated channels are connected to the input ports of a series of programmable optical add/drop switch arrays 500. Here again, any number of add/drop switch arrays can be employed to handle any desired number of channels based on design requirement.

Each add/drop switch array 500 also has a corresponding arrays of output ports, add ports, and drop ports. The add/drop switch array 500 selectively routes channels from the input ports to its drop ports; substitutes channels from the add ports in place of the dropped channels; and routes the remaining input channels and the added channels to the output ports of the add/drop switch array 500.

The array of output channels from the add/drop switch array 500 passes through a regulator 501 which adjustably regulates the optical power level of each channel. The output channels are then combined so that they can be transmitted through a second optical link 15 in the optical network. The means for combining the output channels consists of a second array of interference filters 407 - 410 and a second wavelength slicer network 401. These devices are inherently bi-directional, and therefore can be used to multiplex as well as demultiplex the WDM signal for the optical network. Each of the interference filters 407 - 410 in the second array combine eight channels as an inverse operation of that performed by the first array of interference filters 307-310. The second array of interference filters 407-410 also serve to purity the spectral characteristics of the output channels and reduce cross-talk. Wavelength slicers 405, 406, and 403 in the second wavelength slicer network 401 multiplex the sets of channels from the second array of interference filters 407 - 410 as an inverse operation to the demultiplexing provided by wavelength slicers 303, 305, and 306 in the first wavelength slicer network 301. Similarly, wavelength slicers 404 and 402 combine the express lanes 13 with the

multiplexed channels from the wavelength slicer 403 to reconstitute the entire WDM signal for the optical network.

It should be understood that other means could be readily substituted to combine output channels from the add/drop switch arrays 500 and the express lanes 13 since each channel has a unique wavelength.

FIGURE 5 depicts an add/drop smart switch 590 for use in the switch array 500. The array would be comprised of 32 switches 590, each of which can be individually controlled to selectively replace one of the input channels with one of the add channels. The smart switch 590 is described more fully in Attorney Docket Number 55872-P043CP1-993120, entitled "FIBER OPTIC SMART SWITCH," which is hereby incorporated herein by reference.

The smart switch 590 includes a polarization beam splitter 502 which is shown in Attorney Docket Number 555872-P048US-992837, entitled "HIGH EXTINCTION RATIO POLARIZATION BEAMSPLITTER," which is hereby incorporated herein by reference. The beamsplitter 502 operates to pass p light (horizontal or "|") through the beamsplitting surfaces, and deflects s light (vertical or "•"). Thus, when the input 503 and the add 504 signals are in p light, the input 503 signal is routed to the drop port 506 and the add 504 signal is routed to the output port 505. This mode is known as the add/drop mode. When the input 503 is s light, the input 503 signal is routed to the output port 505. This mode is known as the bypass or pass through mode. Note that in this mode there is no add signal. To properly process the signals, the switch 590 includes a collimator 507 to collimate the input/add light, birefringent separator elements 508 to separate the light into its p and s components and to laterally displace the p and s components.

The birefringent element 508 is made of a material that allows the vertically polarized portion of the optical signal to pass through without changing course because they are ordinary waves in the birefringent element 508. In contrast, horizontally polarized waves are redirected at an angle because of the birefringent walk-off effect. The angle of redirection is a well-known function of the particular materials chosen. Examples of materials suitable for construction of the birefringent elements used in the preferred embodiments include calcite, rutile, lithium niobate, YVO4 based crystals, and the like.

The switch also uses a halfwave plate 509 to change one of the polarization components into the other component, (as shown, the plate changes the s component into p light, however it could be placed in front of the p component) and thus all of the light incident onto the rotator is of the same polarization type. Each output/drop port includes a reverse of the input elements. Note that the halfwave plate on the output port is on the opposite branch from plate 509. This provides balance to the system by having the light from each branch pass through the same number of optical elements. Also, note that since the smart switch 590 performs regulation, the additional regulator 501 is not needed.

The PBS 502 is surrounded by four polarization controllers or rotators 510. The rotators 510 are used to control the polarization of the light received by the PBS . The voltage applied to the rotators causes the light to either pass through unrotated (15 volts) or rotated such that p becomes s and s becomes p (0 volts). For example, if the light incident onto the PBS is made to be p light, the light will pass through the PBS, and if the light is made to be s light, the light will be deflected by the PBS. The switchable polarization rotators 510, 514, 515 can be made of one or more types of known elements including parallel aligned liquid crystal rotators, twisted pneumatic liquid crystal rotators, ferro electric liquid crystal rotators, pi-cell liquid crystal rotators, magneto-optic based Faraday rotators, acousto-optic and electro-optic polarization rotators. Commercially available rotators using liquid crystal based technology are preferred.

The switch 590 includes a partially reflecting mirror 511 which passes about 95% of the incident light, and deflects about 5% of the light. The deflected 5% is indecent onto a detector 512 which measures the amount of light. The controller electronics 513 uses this measurement to control the rotators, as shown input rotator 514 and output rotator 515. Note that the voltage being applied to the rotators can be varied between 0-15 volts, the voltage level determines how much of the light is rotated.

By controlling the voltage level to the input rotator 514, the add/drop switch can have a drop and continue operation. For example, if the rotator 514 changes both branches of the input signal to half p and half s, then half of the input signal will be routed to the drop port 506, and half of the input signal will be routed to the output port 505. This operation allows for the input signal to be split, and thus shared between two network components. The operation also

allows for the regulation/attenuation of the output signal 505 by shunting a portion of the input signal to the drop port. This prevents the output signal 505 from this switch to be greater than output signals from other switches in the array 500. The add signal can be similarly controlled. Note that by controlling the output rotator 515, the output signal can also be controlled in such a manner.

As shown in FIGURE 5, the input signal is split into two components during processing, and recombined by a birefringent element 516 prior to outputting. The output rotator 515 can introduce both p and s polarizations into each branch of the signal. Normally, the vertical branch 517 passes through the element, and thus the output collection point 519 is located along this path. The horizontal branch 518 is deflected into the path of the vertical branch 517 for collection. However, if the vertical branch 517 has been changed to include a horizontal component, then this component is deflected out of the element and away from the collection point 519. Similarly, if the horizontal branch 518 has been changed to include a vertical component, then this component will pass through the element and away from the collection point 519. Thus, this rotator 505 will provide for regulation/attenuation of the output signal. The drop signal can be similarly controlled.

The array of add/drop switches can be formed in matrix arrangement to allow for interconnection or cross-connection of the add and drop ports. FIGURE 6 depicts a 4 x 4 array 1000 of PBSs 700. In front of each input path to each respective PBS is a polarization controller (not shown) which controls the polarization of the light entering the respective PBS, i.e., the controller could change the light such that the light incident onto the PBS is p light or s light. In the add/drop mode, where the input goes to drop, and the add goes to output, each of the add signals, ABCD, would go to a respective output path, 5678. Similarly, each input signal, EFGH, would go to a respective drop path, 1234. The add/drop mode is accomplished by setting the various rotators to emit only p light.

In the bypass mode, each input signal, EFGH, could be directed to any one of the outputs paths 5678. Thus, inputs EFGH could be outputted to 5768, 5867, etc. The bypass mode is accomplished by setting particular ones of the rotators to s light. For example, to have the E input switched to output 6, the input rotator for unit 1001 would be set to provide s light to the unit. The other units in the E input column would be set to provide p light such that the

light would pass through the PBSs, until encountering unit 1001. The output rotator from 1001 would be set to provide p light such that the light passes through the units of the output 6 row, and consequently be delivered to output 6. Thus, the various rotators are used to control the polarization of the light that is incident onto the various PBSs of the switch module, and thus control their connection.

Note that various combinations of the switch and pass through states can be achieved. For example, input E could be routed to drop, inputs FGH could be routed to outputs 567, respectively, and add D could be routed to output 8. As general rules, input E can be routed to any of 15678, input F can be routed to any of 25678, input G can be routed to any of 35678, input H can be routed to any of 45678, while input A can be routed to 5, input B can be routed to 6, input C can be routed to 7, and input D can be routed to 8. Note that the 4 x 4 arrangement is by way of example only, as the PBS can be arranged in a N x M array, see "N x M DIGITALLY PROGRAMMABLE OPTICAL ROUTING SWITCH USING HIGH EXTINCTION RATIO POLARIZATION BEAM SPLITTER," Attorney Docket Number 55872-P046CP1CP1-993118, which is incorporated herein by reference. The switch described above is actually more than 4 x 4, as defined by the conventional definition. It has a total of 16 ports, 4 input and 4 output ports are cross connected. The other set of 4/4 input/output ports are used for add/drop operation. This feature is not available in the prior art. Note that each of the switches in the array may be a smart switch, and thus have its respective rotators controlled by varying the applied voltage based on the output (or drop) light.

FIGURE 7 depicts an arbitrary add/drop switch 1100. This switch is comprised of two 4 x4 modules of FIGURE 6, note that only one set of input/output elements are needed. This arrangement permits any input signal ABCD to be dropped to any drop path 1234. Similarly any add signal EFGH can be delivered to any output path 5678. Also the input signals ABCD can be passed through to their respective output paths 5678. Again, each of the switches in the array may be a smart switch, and thus have its respective rotators controlled by varying the applied voltage based on the output (or drop) light. This arrangement allows for a mesh type connection, as shown in FIGURE 13, and thus is useable with internet protocol (IP). Consequently, IP protocol data can be routed over WDM.

bandwidth is needed, then more express lanes could be created. This is shown in FIGURE 13 by the different thickness of lines, including higher bandwidths (or smaller signal spacing, e.g. 50GHz) and numbers of lines (numbers of fibers).

FIGURE 8 depicts the arbitrary add/drop switch of FIGURE 7 with wavelength conversion. In addition to operations described in FIGURE 7, each input signal λ1, λ2, λ3, λ4, can be routed to any of the detectors 1101, where each signal is converted into an electrical signal and processed by electronics 1102. The output electrical signal are then sent to respective lasers 1103 for retransmission as light. Each light output from the lasers can be routed to any of the output paths. Again, each of the switches in the array may be a smart switch, and thus have its respective rotators controlled by varying the applied voltage based on the output (or drop) light.

Each of the types of add/drop switches would provide the network of FIGURE 4 with different operating capabilities. Note that other add/drop switches as described in Attorney Docket Number 555872-P042CP2CP1-993119, entitled "OPTICAL ADD/DROP WAVELENGTH SWITCH USING A HIGH EXTINCTION RATIO POLARIZATION BEAMSPLITTER," which is incorporated herein by reference, could be used herein as array 500.

Also note that the network of FIGURE 4 could be protected according to the fault handling mechanisms described in U.S. Application Serial Number 09/190,078, entitled "SYSTEM FOR DEALING WITH FAULTS IN AN OPTICAL LINK," filed November 12, 1998, which is incorporated herein by reference. This type of OS protection is useful for handling IP protocol data. Layer 3 protection is provided by the internet protocol.

FIGURE 9 depicts a drop/add switch for wavelength management and restoration. Note that FIGURE 9 includes four fibers 1201, and four 4 x 4 modules 1203. Note that the number of fibers is by way of example only, as more fibers would merely require a scaled drop/add switch. Also note that the modules are shown as being only partially connected to DEMUXes and MUXes to simplify the figure. Further note that λ1, λ2, λ3, and λ4, can be viewed as λb (blue), λg (green), λy (yellow), and λr (red). Each fiber carries different signals which are encoded by wavelength, e.g. λ1, λ2, λ3, λ4. These signals are demultiplexed by DEMUX 1202. Each wavelength from each fiber is provided to a particular 4 x 4 module, e.g.

$\lambda 1$ from each of the four fibers is provided to module 1203. Within each module 1203, the operations are as described with respect to FIGURE 6. Thus, particular signals can be dropped or added or re-routed to the output. Note that the diagonal slash through each module indicates the orientation of the PBSs within the module. For a further discussion on multiple wavelength management, see related application "MULTI-WAVELENGTH CROSS CONNECT OPTICAL NETWORK," Application Serial Number 08/907,551, which is incorporated herein by reference.

FIGURE 10 depicts a multi-ring network system 2000 connecting seven nodes A, B, C, D, E, F, and G. Note that the ring connecting DEFG is connected by an OS-200-4 line, while another OS-200-4 line ring connects ADC, without connecting B. The ABC ring is connected by an OS-200-2 line. The OS-200-1 ring connects ABCD, and OS-200-3 ring connects nodes BCD. The various switches described above allow this network to have express connections, to perform local add/drops of signals. For example, node E could comprise a the switch shown in FIGURE 6, where the OS-200 is sliced down to four OS-800 signals and can perform add/drops to those signals. Node D could comprise the wavelength cross-connect switch shown in FIGURE 9 to cross-connect the OS-200-4 fibers. As shown in FIGURE 11, each OS-200-4 signals can be divided into four OS-800 signals. Note that FIGURE 9 would be simplified in this case, as it would have four 4 x4 switches with two input DEMUXs. The two OS-200-4 fibers would be inputted into the input DEMUXs, and processed into the switches from there, an OS-800 signal from one of the fibers can be connected into the other input line, or other signals can be added into the lines, etc.

As shown in FIGURE 12 a cross-connected node, such as node D in FIGURE 10, empty slots can be filled via wavelength slot interchange. For example, train 4000 has empty slots 4001, 4002. These may be filled via a add/drop switch with wavelength conversion as shown in FIGURE 8. In other words, a signal can have its wavelength changed, and be added into an empty slot. Also the wavelength cross-connect switch shown in FIGURE 9 can be used to move a signal with the same wavelenght from a different train in the empty slot.

The above disclosure sets forth a number of embodiments of the present invention. Other arrangements or embodiments, not precisely set forth, could be practiced under the teachings of the present invention and as set forth in the following claims.

Other types of frequency multiplexers and demultiplexers could be readily substituted in place of the wavelength slicers 101-104 shown in FIGURES 1-3. For example, a set of polarization rotators and a polarized beamsplitter can be used to combine the first and second sets of channels, in place of wavelength slicers 101 and 102 in terminal 1. Demultiplexing can be accomplished by filters or diffraction gratings, although such approaches would tend to be less efficient and more expensive.

Although the present invention and its advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of the invention as defined by the appended claims. Moreover, the scope of the present application is not intended to be limited to the particular embodiments of the process, machine, manufacture, composition of matter, means, methods and steps described in the specification. As one of ordinary skill in the art will readily appreciate from the disclosure of the present invention, processes, machines, manufacture, compositions of matter, means, methods, or steps, presently existing or later to be developed that perform substantially the same function or achieve substantially the same result as the corresponding embodiments described herein may be utilized according to the present invention. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or steps.

WHAT IS CLAIMED IS:

1. An optical wavelength add/drop multiplexer providing communications between a first optical link and a second optical link using wavelength division multiplexing (WDM) to support a plurality of channels, said multiplexer comprising:

a wavelength slicer spatially separating channels from the first optical link into a first set of channels and a second set of channels;

an optical filter spatially separating at least a subset of said first set of channels into an array of separated channels;

a programmable optical add/drop switch array having an array of input ports receiving said separated channels, an array of output ports, an array of add ports, and an array of drop ports; wherein said add/drop switch array selectively routes channels from said input ports to said drop ports, substitutes channels from said add ports in place of said channels routed to said drop ports, and routes the remaining input channels and added channels to said output ports; and

means for combining channels from said output ports of said add/drop switch array into the second optical link.

2. The optical wavelength add/drop multiplexer of claim 1, wherein said optical filter comprises an array of interference filters.

3. The optical wavelength add/drop multiplexer of claim 1, wherein said wavelength slicer further comprises means for spatially separating alternating adjacent channels from the first optical link into said first and second sets of channels.

4. The optical wavelength add/drop multiplexer of claim 1 wherein said wavelength slicer comprises:

a first polarization-dependent routing element spatially separating said channels from the first optical link into a pair of orthogonally-polarized beams;

a polarization rotator for rotating the polarization of at least one of said pair of orthogonally-polarized beams to create first and second beams having the same polarization;

a wavelength filter coupled to receive said first and second beams from said polarization rotator, said wavelength filter having a polarization dependent optical transmission function such that the said first beam decomposes into third and fourth beams with their polarizations orthogonal to each other, and said second beam decomposes into fifth and sixth beams with their polarizations orthogonal to each other, wherein said third and fifth beams carry said first set of channels at a first polarization and said fourth and sixth beams carry said second set of channels at a second polarization, wherein said first and second polarizations are orthogonal; and

a second polarization-dependent routing element especially routing said third and fifth beams carrying said first set of channels along a first optical path and said fourth and sixth beams carrying said second set of channels along a second optical path based on their polarizations.

5. The optical wavelength add/drop multiplexer of claim 4, wherein said wavelength filter comprises a stacked plurality of birefringent waveplates with each waveplate oriented in a predetermined direction.

6. The optical wavelength add/drop multiplexer of claim 1, wherein said programmable optical add/drop switch having a bridge state and an add/drop state determined by an external control state, with said add/drop switch having:

an input port receiving an optical input signal;

an output port;

an add port receiving an optical add signal;

a drop port;

a first polarization-dependant routing element for spatially separating said input signal into a pair of orthogonally-polarized pair of add beams;

a first polarization rotator selectively rotating the polarization of at least one of said input beams so that both input beams have the same polarization determined by the control state, and selectively rotating the polarization of at least one of said add beams so that both of said add beams have the same polarization determined by the control state;

a wavelength filter coupled to receive said input beams from said first polarization-dependant optical transmission function such that said input beams decompose into two pairs of orthogonally -polarized beams components, wherein one of each pair of orthogonally-polarized beam components carries a predetermined spectral drop band at first polarization and the other of each pair of orthogonally-polarized beam components carries a predetermined spectral pass-through band at a second polarization, wherein said drop band and said pass-through band are substantially complementary and said first and second polarizations are orthogonal;

a second polarization-dependant routing element spatially-separating said pass-through beam components and said drop beam components based on their polarizations;

a second polarization rotator selectively rotating the polarization of said spatially-separated beam components determined by the control state;

a third polarization-dependant routing element combining and routing said add beams and said pass-through beam components along a pair of output optical paths, and routing said drop beam components along a pair of drop optical paths in said add/drop state; and combining and routing said drop beam components and said pass-through components along said output optical paths, and routing said add beams along said drop optical paths in said bridge state;

a third polarization rotator selectively rotating the polarization of at least one of the pair of output beams such that said output beam is orthogonally polarized, and rotating the polarization of at least one of the pair of drop beams such that said drop beam pair is orthogonally polarized; and

a polarization combining element combining said orthogonally-polarized output beam pair at said output port, and combining said orthogonally-polarized drop beam pair at said drop port.

7. The optical wavelength add/drop multiplexer of claim 1, further comprising:

means for combining said second set of channels with said channels form said output ports of said add/drop switch into the second optical link.

8. The optical wavelength add/drop multiplexer of claim 1, further comprising:

at least a second stage of at least one wavelength slicer spatially separating alternating channels from said first set of channels into a plurality of subsets of said first set of channels.

9. The optical wavelength add/drop multiplexer of claim 8, wherein said stages of wavelength slicers comprise a binary tree network of wavelength slicers.

10. An optical wavelength add/drop multiplexer providing communications between a first optical link and a second optical link using wavelength division multiplexing (WDM) to support a plurality of channels, said multiplexer comprising:

a first wavelength slicer spatially separating alternating channels from the first set of channels and a second set of channels;

a least a second stage of at least one wavelength slicer spatially separating alternating channels from said first set of channels into a plurality of subsets of said first set of channels;

an optical filter spatially separating at least one said subsets of said first set of channels into an array of separated channels;

a programmable optical add/drop switch array having an array of input ports receiving said separated channels, an array of output port, an array of add ports, and an array of drop ports, wherein said add/drop switch array selectively routes channels from said input ports to said drop ports, substitutes channels from said add ports in place of the dropped channels, and routes the remaining input channels and added channels to said output ports; and

11. The optical wavelength add/drop multiplexer of claim 10, wherein said optical filter comprises an array of interference filters.

12. The optical wavelength add/drop multiplexer of claim 10, wherein said stages of wavelength slicers comprise a binary tree network of wavelength slicers.

13. The optical wavelength add/drop multiplexer of claim 10, further comprising:

means for combining said second set of channels with said channels from said output ports of said add/drop switch into the second optical link.

14. The optical wavelength add/drop multiplexer if claim 10, wherein said wavelength slicer comprises:

a first polarization-dependant routing element spatially separating said channels form the first optical link into a pair of orthogonally-polarized beams;

a polarization rotator for rotating the polarization of at least one of said pair of orthogonally-polarized beams to create and second beams having the same polarization;

a wavelength filter coupled to receive said first and second beams from said polarization rotator, said wavelength filter having a polarization-dependant optical transmission function such that the said first beam decomposes into third and fourth beams with their polarizations orthogonal to each other and said second beam decomposes into fifth and sixth beams with their polarizations orthogonal to each other, wherein said third and fifth beams carry said first set of channels at first polarization and said fourth and sixth beams carry said second set of channels at a second polarization, wherein said first and second polarizations are orthogonal; and

a second polarization-dependent routing element spatially routing said third and fifth beams carrying said first set of channels along a first optical path and said fourth and sixth beams carrying said second set of channels along a second optical path based on their polarizations.

15. The optical wavelength add/drop multiplexer of claim 10, wherein said programmable

bridge state and an add/drop state determined by an external control state, with said add/drop switch comprising:

an input port receiving an optical input signal;

an output port;

an add port receiving an optical add signal;

a drop port;

a first polarization-dependent routing element for spatially separating said input signal into a pair of orthogonally-polarized input beams, and spatially separating said add signal into an orthogonally-polarized pair of add beams;

a first polarization rotator selectively rotating the polarization of at least one of said input beams so that both input beams have the same polarization determined by the control state, and selectively rotating the polarization of at least one of said add beams so that both of said add beams have the same polarization determined by the control state;

a wavelength filter coupled to receive said input beams from said first polarization rotator, said wavelength filter having a polarization-dependent optical transmission function such that said input beams decompose into two pairs of orthogonally-polarized beam components, wherein one of each pair of orthogonally-polarized beam components carries a predetermined spectral pass-through band at a second polarization, wherein said drop band and said pass-through band are substantially complementary and said first and second polarizations are orthogonal;

a second polarization-dependent routing element spatially separating said pass-through beam components and said drop beam components based on their polarizations;

a second polarization rotator selectively rotating the polarization of said spatially-separated beam components determined by the control state;

a third polarization-dependent routing element combining and routing said add beams and said pass-through beam components along a pair of output optical paths, and routing said drop beam components along a pair of drop optical paths in said add/drop state; and combining and routing said drop beam components and said pass-through beam components along said

output optical paths, and routing said add beams along said drop optical paths in said bridge state;

a third polarization rotator selectively rotating the polarization of at least one of the pair of output beams such that said output beam pair is orthogonally polarized, and rotating the polarization of at least one of the pair of drop beams such that said drop beam pair is orthogonally polarized; and

a polarization combining element combining said orthogonally-polarized output beam pair at said output port, and combining said orthogonally-polarized drop beam pair at said drop port.

16. An optical wavelength add/drop multiplexer providing communications between a first optical link and a second optical link using wavelength division multiplexing (WDM) to support a plurality of channels, said multiplexer comprising:

a wavelength slicer spatially separating channels from the first optical link into a first set of channels and a second set of channels;

a circulated drop filter spatially separating at least a subset of said first set of channels into a third set of channels and a fourth set of channels;

an optical filter spatially separating at least a subset of said third set of channels into an array of separated channels;

a programmable optical add/drop switch array having an array of input ports receiving said separated channels, an array of output ports, an array of add ports, and an array of drop ports; wherein said add/drop switch array selectively routes channels from said input ports to said drop ports, substitutes channels from said add ports in place of the dropped channels, and routes the remaining input channels and added channels to said output ports; and

means for combining channels from said output ports of said add/drop switch array into said second optical link.

17. The optical wavelength add/drop multiplexer of claim 16, further comprising:

means for combining said fourth set of channels with said channels from said output ports of said add/drop switch into the second optical link.

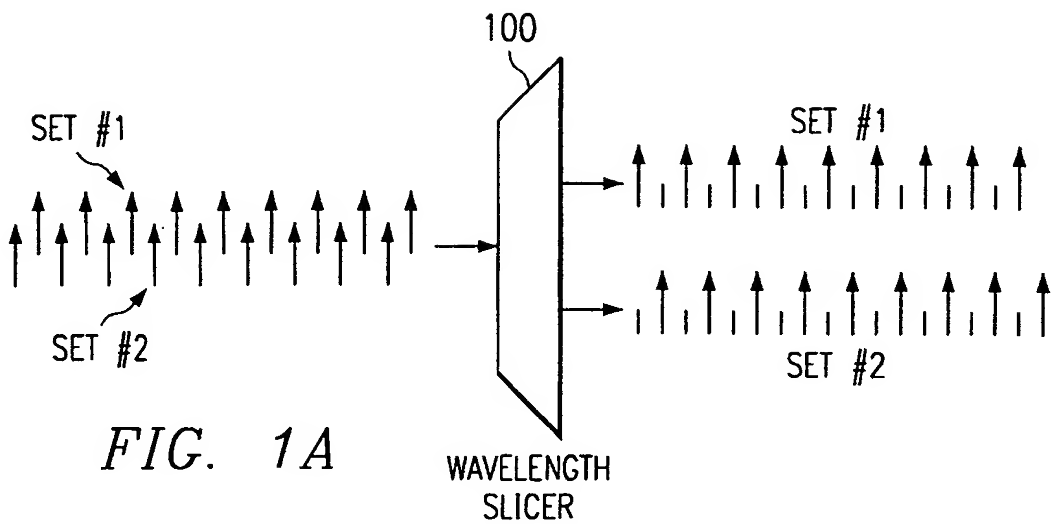
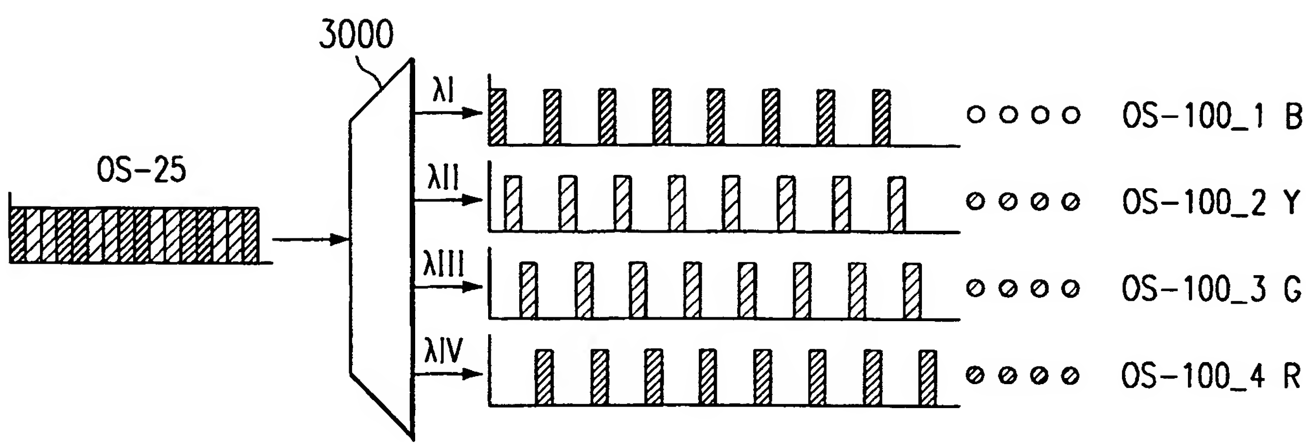


FIG. 1A



OPTICAL SLICING

1	OS-25	200*2.5 Gbps
2	OS-50	100*2.5 Gbps
4	OS-100	50*2.5 Gbps
8	OS-200	25*2.5 Gbps

ASSUMING EDFA 40 nm BAND

SONET

1	OC-192	10 Gbps
4	OC-48	2.5 Gbps
16	OC-12	622 Mbps
64	OC-3	155 Mbps

FIG. 1B

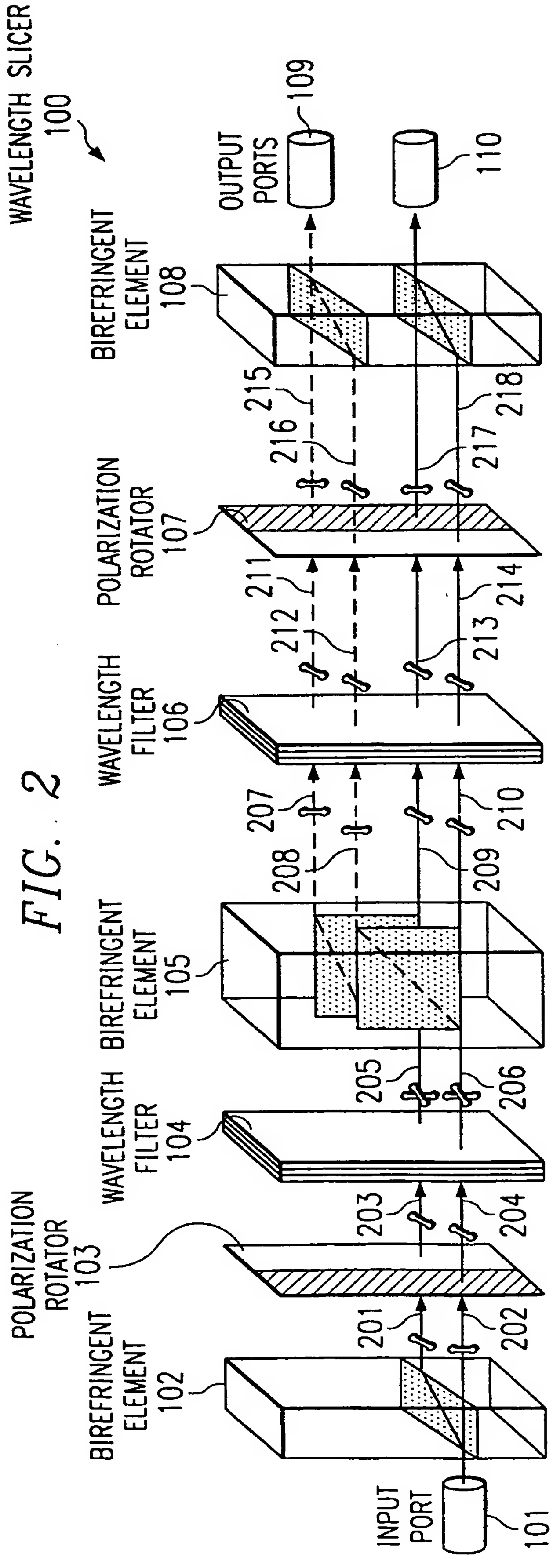

WAVELENGTH SLICER 100
INPUT PORT
101
BIREFRINGENT ELEMENT 102
201
202
POLARIZATION ROTATOR 103
203
204
WAVELENGTH FILTER 104
205
206
BIREFRINGENT ELEMENT 105
207
208
209
210
WAVELENGTH FILTER 106
211
212
213
214
POLARIZATION ROTATOR 107
215
216
217
218
BIREFRINGENT ELEMENT 108
OUTPUT PORTS
109
110

FIG. 2

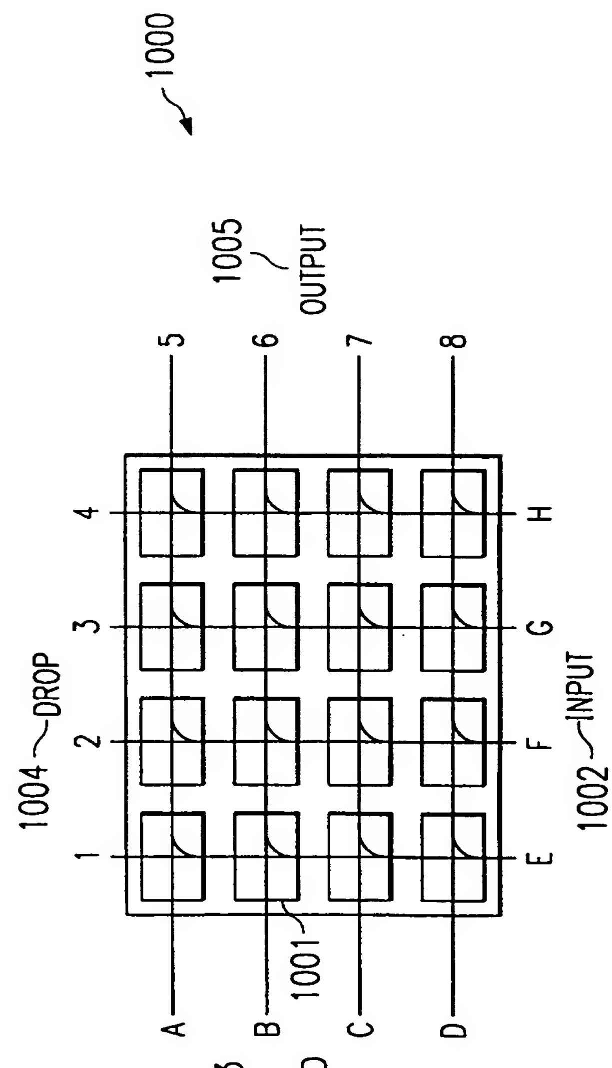

1000
1001
1002 INPUT
1003 ADD
1004 DROP
1005 OUTPUT
A
B
C
D
E
F
G
H
1
2
3
4
5
6
7
8

FIG. 6

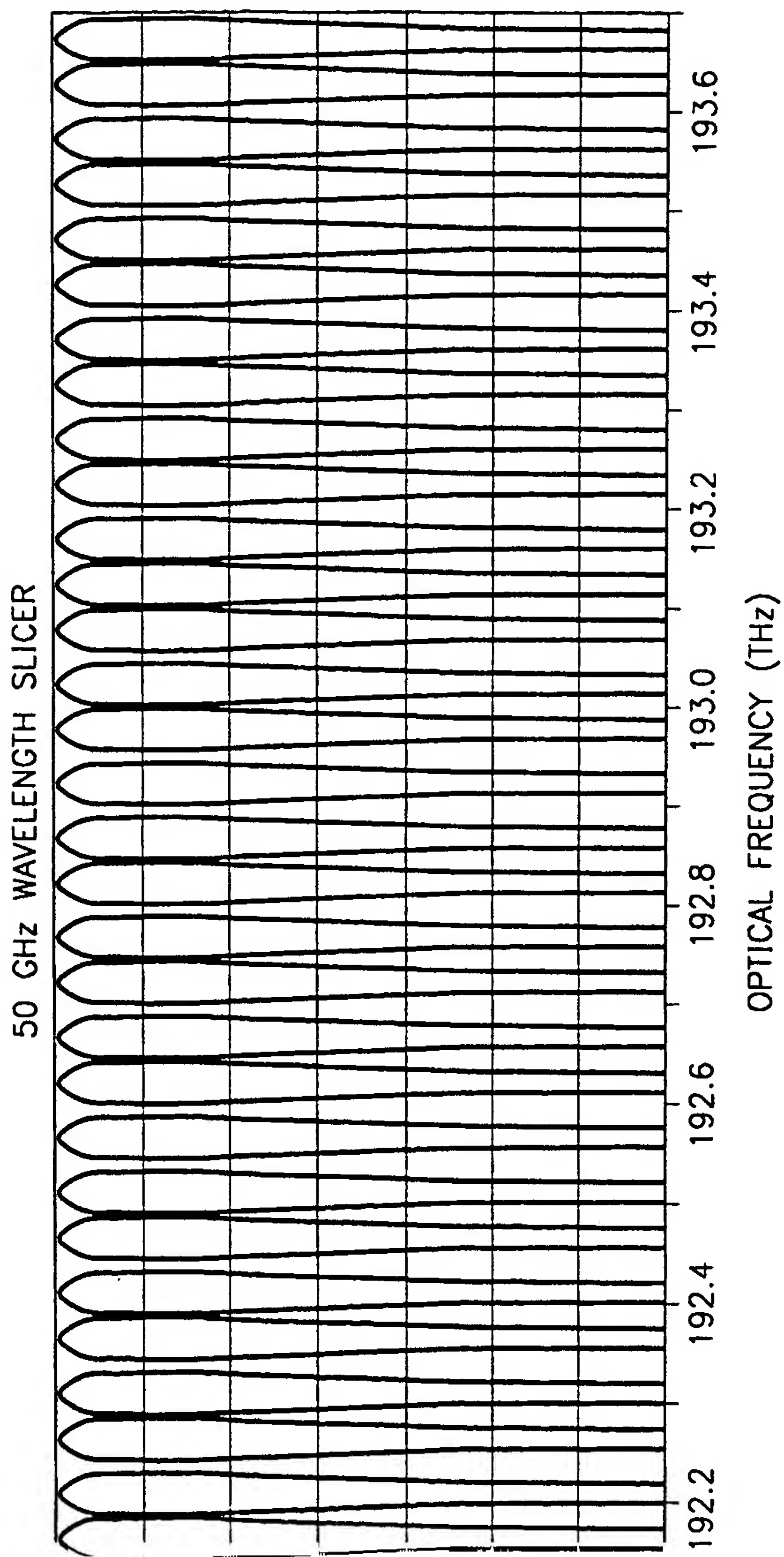

50 GHz WAVELENGTH SLICER
193.6
193.4
193.2
193.0
192.8
192.6
192.4
192.2
OPTICAL FREQUENCY (THz)

FIG. 3

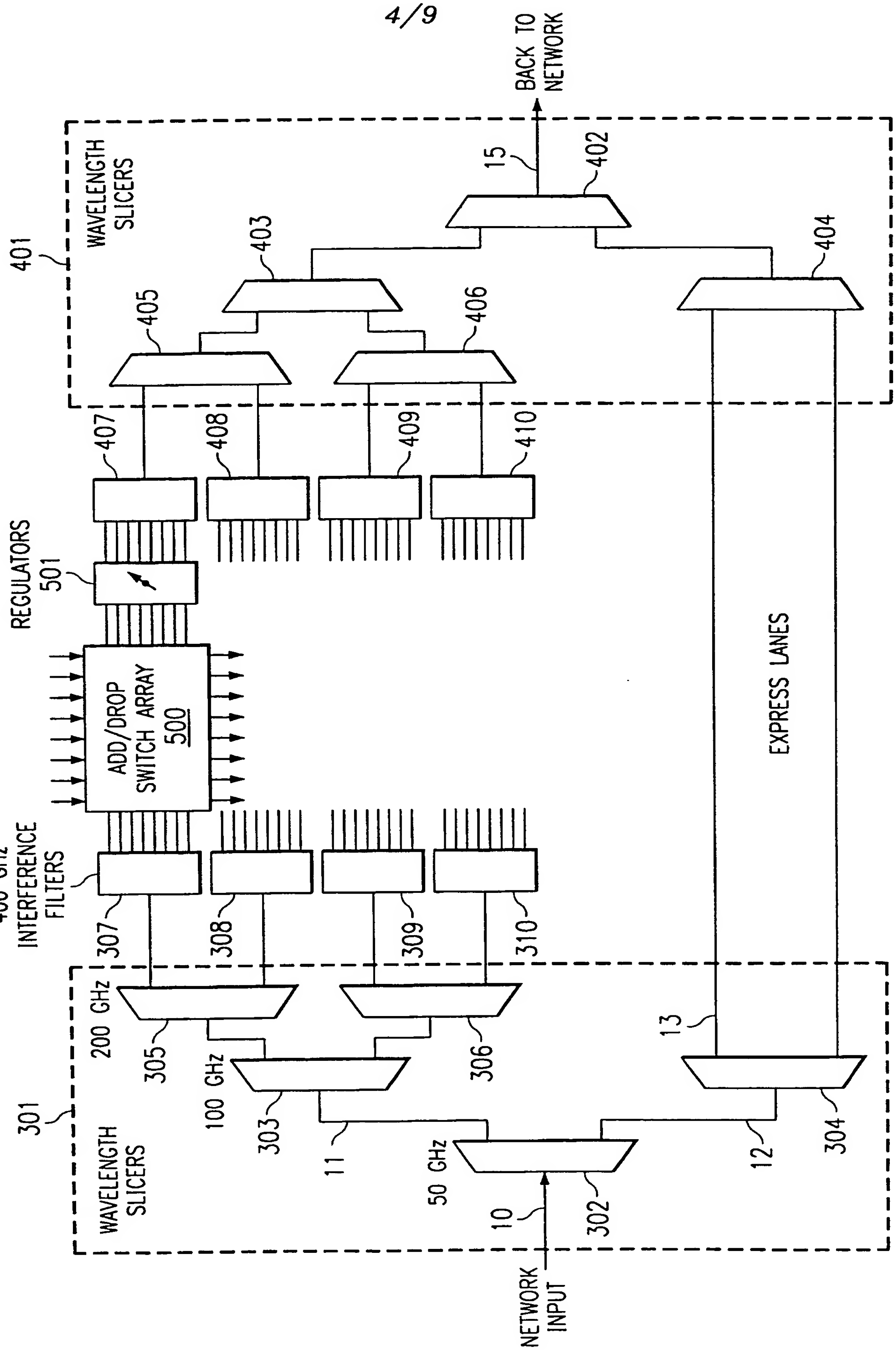

BACK TO NETWORK
15
402
WAVELENGTH SLICERS
401
403
404
405
406
407
408
409
410
REGULATORS
501
ADD/DROP SWITCH ARRAY
500
400 GHz INTERFERENCE FILTERS
307
308
309
310
EXPRESS LANES
200 GHz
305
306
100 GHz
303
13
301
WAVELENGTH SLICERS
11
50 GHz
12
304
10
302
NETWORK INPUT

FIG. 4

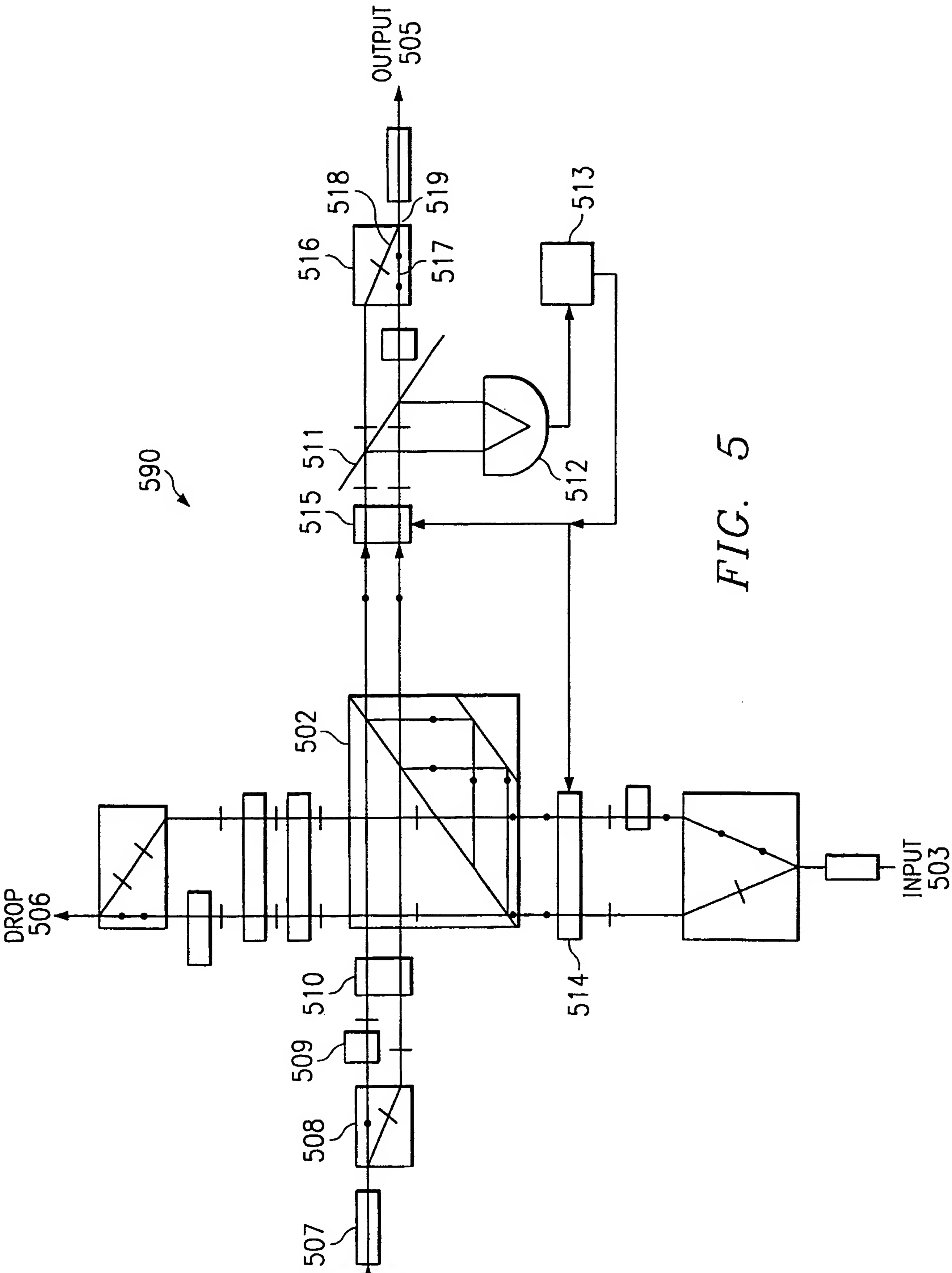

OUTPUT
505
518
519
516
517
513
590
511
515
512
502
DROP
506
INPUT
503
510
509
508
507
514

FIG. 5

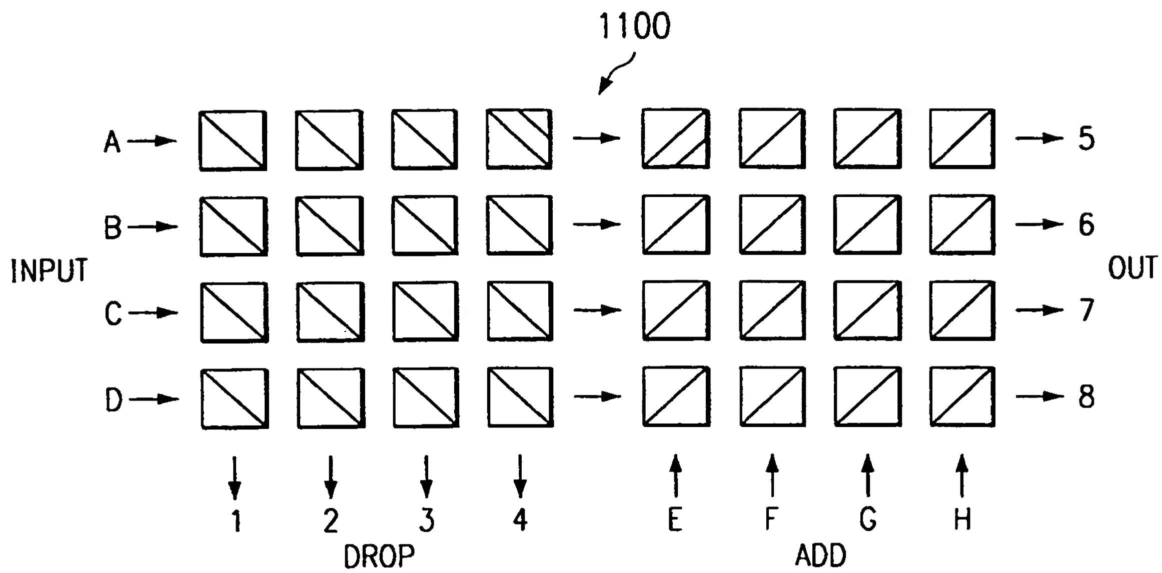

1100
A
B
C
D
INPUT
5
6
7
8
OUT
1
2
3
4
DROP
E
F
G
H
ADD

FIG. 7

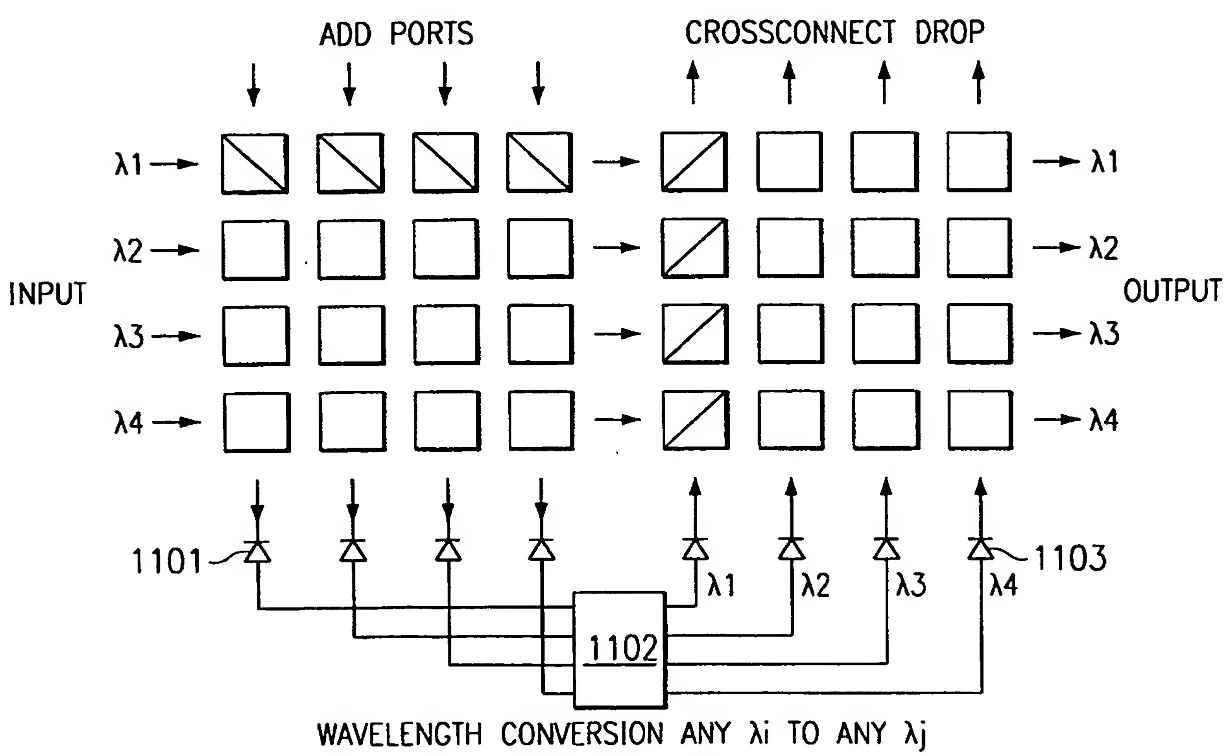

ADD PORTS
CROSSCONNECT DROP
λ1
λ2
λ3
λ4
INPUT
OUTPUT
1101
1102
1103
λ1
λ2
λ3
λ4
WAVELENGTH CONVERSION ANY λi TO ANY λj

FIG. 8

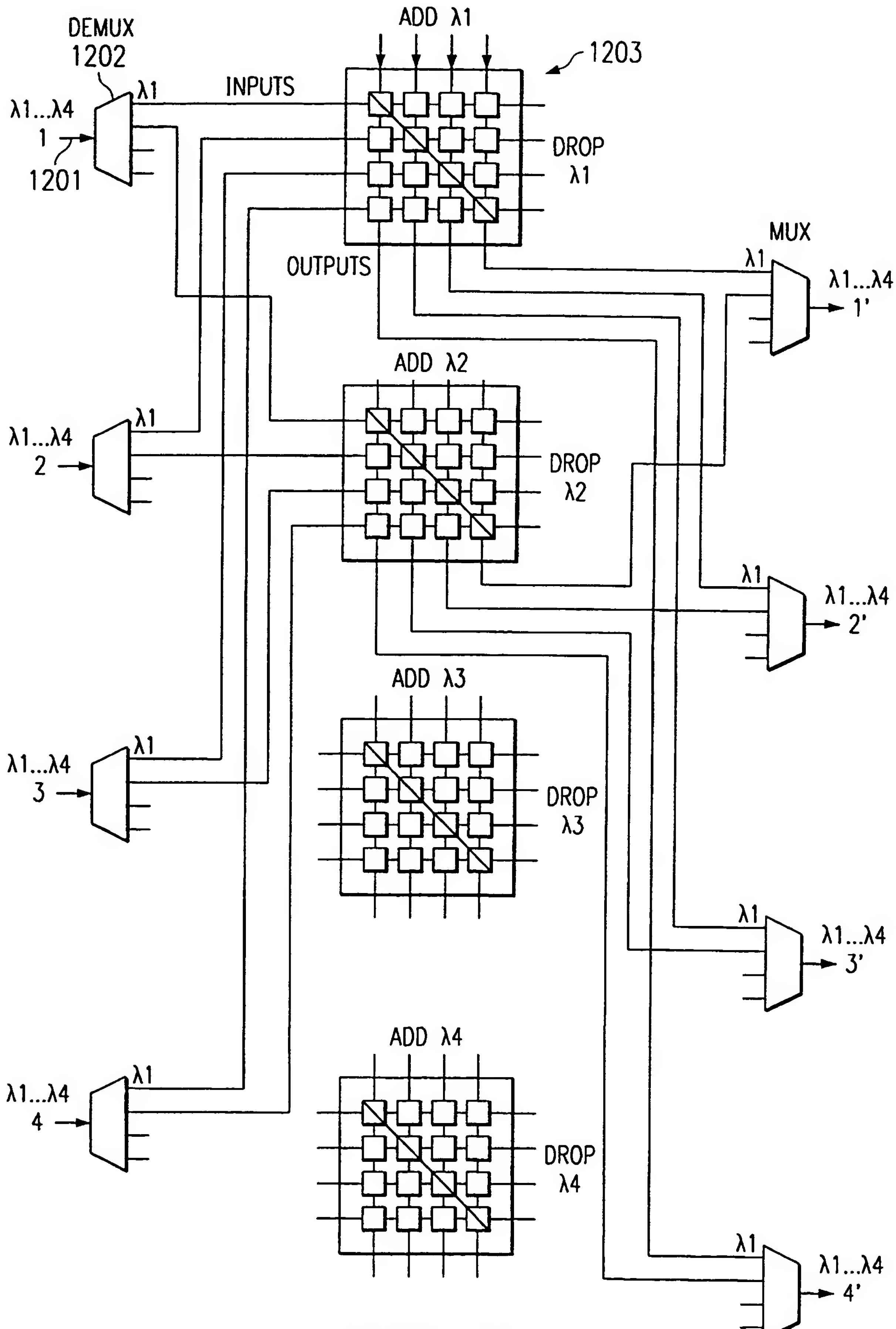

DEMUX
1202
ADD λ1
1203
λ1...λ4
1
1201
λ1
INPUTS
DROP
λ1
OUTPUTS
MUX
λ1
λ1...λ4
1'
ADD λ2
λ1...λ4
2
λ1
DROP
λ2
λ1
λ1...λ4
2'
ADD λ3
λ1...λ4
3
λ1
DROP
λ3
λ1
λ1...λ4
3'
ADD λ4
λ1...λ4
4
λ1
DROP
λ4
λ1
λ1...λ4
4'

FIG. 9

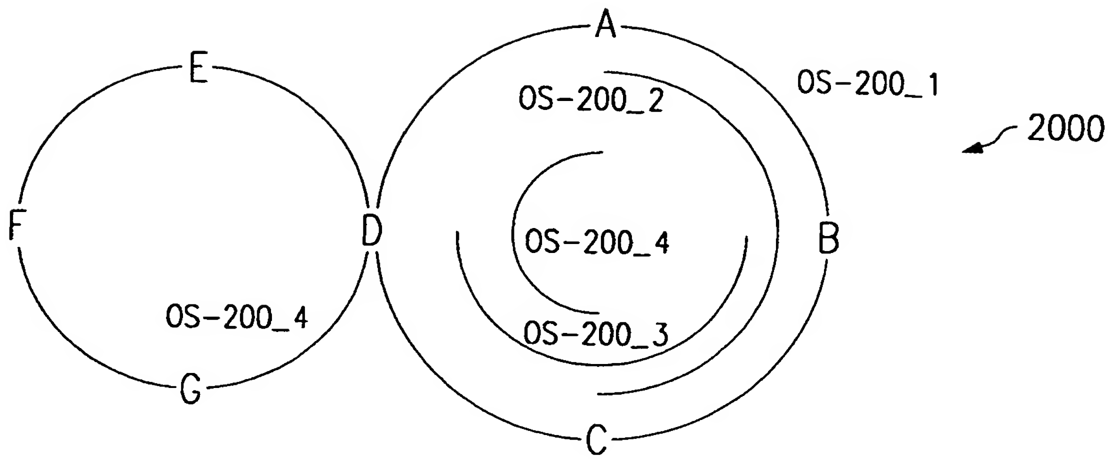

A
E
OS-200_2
OS-200_1
2000
F
D
OS-200_4
B
OS-200_4
OS-200_3
G
C

FIG. 10

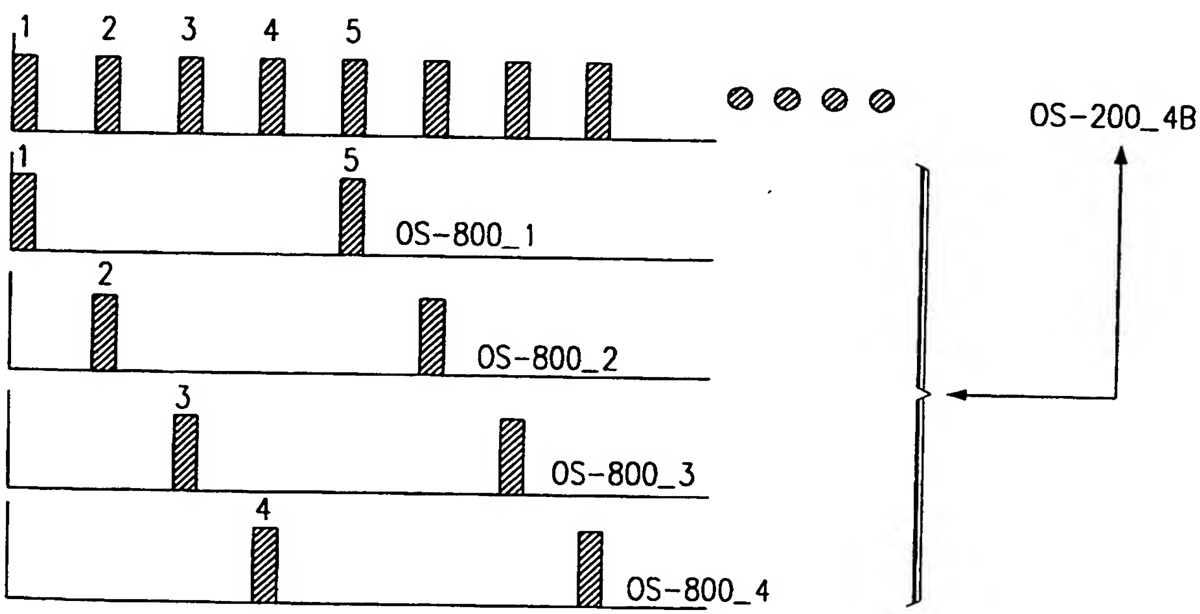

1
2
3
4
5
OS-200_4B
1
5
OS-800_1
2
OS-800_2
3
OS-800_3
4
OS-800_4

FIG. 11

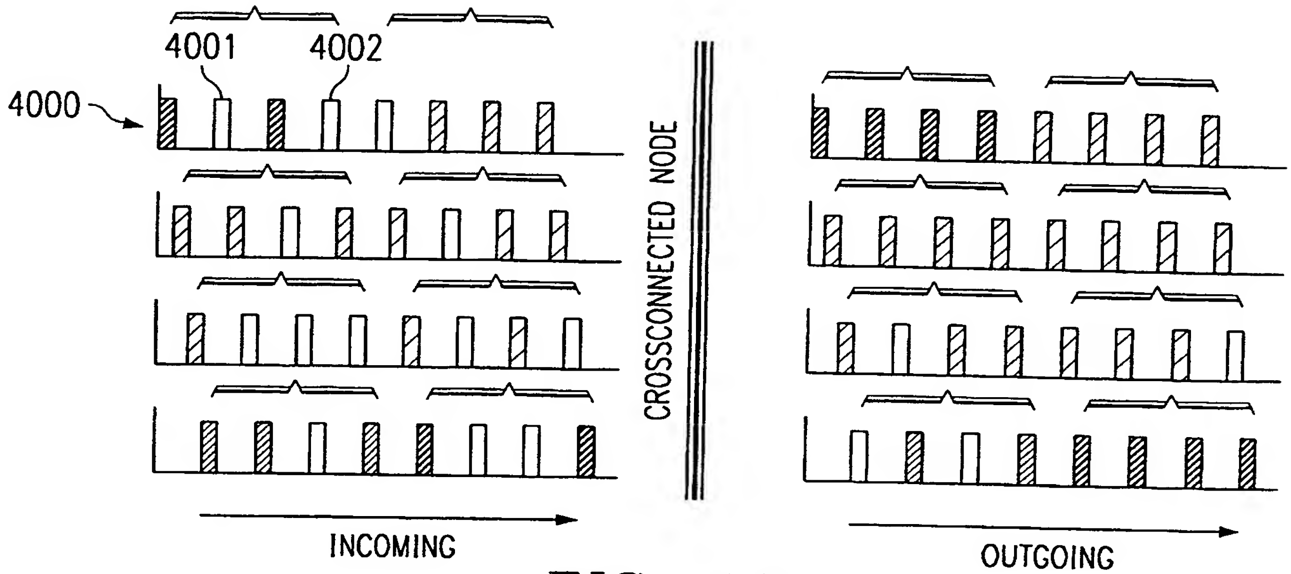


FIG. 12

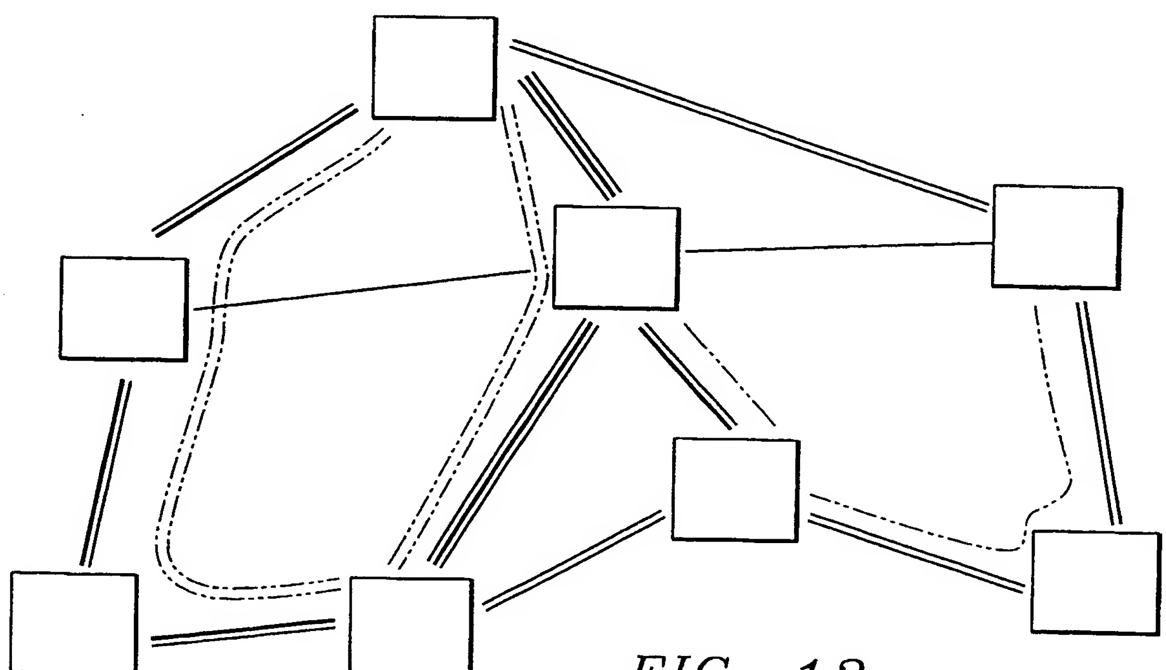


FIG. 13

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/15431

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04J14/02 H04Q11/00 G02F1/31

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04J H04Q G02F G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	EP 0 905 936 A (CAMBRIAN SYSTEMS CORP) 31 March 1999 (1999-03-31) column 1, line 3 - line 5 column 2, line 34 -column 3, line 38 column 3, line 56 -column 4, line 9 column 5, line 32 -column 6, line 54; figures 3,4 column 10, line 32 -column 11, line 10 ---	1,2,7, 16,17 3-6,8-15
Y	US 3 501 640 A (HARRIS THOMAS J) 17 March 1970 (1970-03-17) column 1, line 33 - line 41 column 2, line 16 -column 3, line 51; figures 1,8 --- -/--	3,8-13

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 September 2000	26/09/2000

Name and mailing address of the ISA	Authorized officer
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